

Reshimming Tevatron Dipoles During the Fall 2003 Shutdown

TD-04-004

J. Blowers, J. Carson, R. Hanft, D. Harding, G. A. Smith

Abstract

During the fall 2003 Lab-wide shutdown, Technical Division personnel performed reshimming operations on 106 installed Tevatron dipoles. This reshimming was done to reposition the coils relative to the iron yoke, in order to minimize the skew quadrupole harmonic. The skew quadrupole harmonic creates coupling between the horizontal and vertical betatron oscillations, which in turn has a negative impact on the circulating beam. Therefore, minimizing the skew quadrupole harmonic is advantageous to the operating of the Tevatron. This paper is written as a summary of the planning and implementation of the reshimming, with the goal of understanding how we can improve upon this work, if called upon to reshim more magnets in the future.

Background

In the Tevatron the horizontal and vertical betatron oscillations have been strongly coupled for over a decade, requiring the skew quadrupole correction circuits to run at about 60% of the maximum current. Don Edwards and Mike Syphers have recently reported¹ on new beam measurements that show the source of the coupling to be distributed fairly uniformly around the ring, rather than concentrated in one or a few locations. Their analysis of several different measurements concludes that the strength of the coupling is consistent with a skew quadrupole component in each dipole of approximately one "unit" (parts in 10^4 at one inch).

The coupling is corrected globally, but the removal in 1991 of spools with skew quad correctors on each side of each interaction point to make room for new low beta insertion components leaves the coupling uncorrected locally through these two sensitive regions. Tracking studies by Norman Gelfand have shown that overall the skew quad component in the dipoles leads to, among other things, a vertical dispersion of 0.5 meters, with the majority coming from the intersection regions. Other unpleasant effects of not having the coupling corrected locally can be imagined.

Meanwhile, in early 2003, Technical Division measured the "cold lift" of 84 dipoles installed in the Tevatron. Comparison of these measurements with production data suggests that the collared coil has dropped approximately 0.11 mm (4.2 mil) in most magnets, presumably due to creep in the G10/G11 suspension pieces that position the collared coil relative to the iron yoke. This would lead to a change in the skew quadrupoles of 1.1 units. There was no indication of horizontal movement.

The good agreement between the beam measurements and the magnet measurements makes a convincing case that the magnet changes are the source of the beam coupling.

¹ Document available from <http://beamdocs.fnal.gov/DocDB/0005/000501/003/EXP203.pdf>

Dipole Design

The Tevatron dipole magnets are characterized by a so-called warm-yoke design, in which the magnetic yoke is not included in the low temperature cryostat surrounding the superconducting coils. The cryostated coils are held within the warm yoke in nine so-called support stations, spaced at ~ 0.73 m intervals along the ~ 6 m long magnetic yoke.

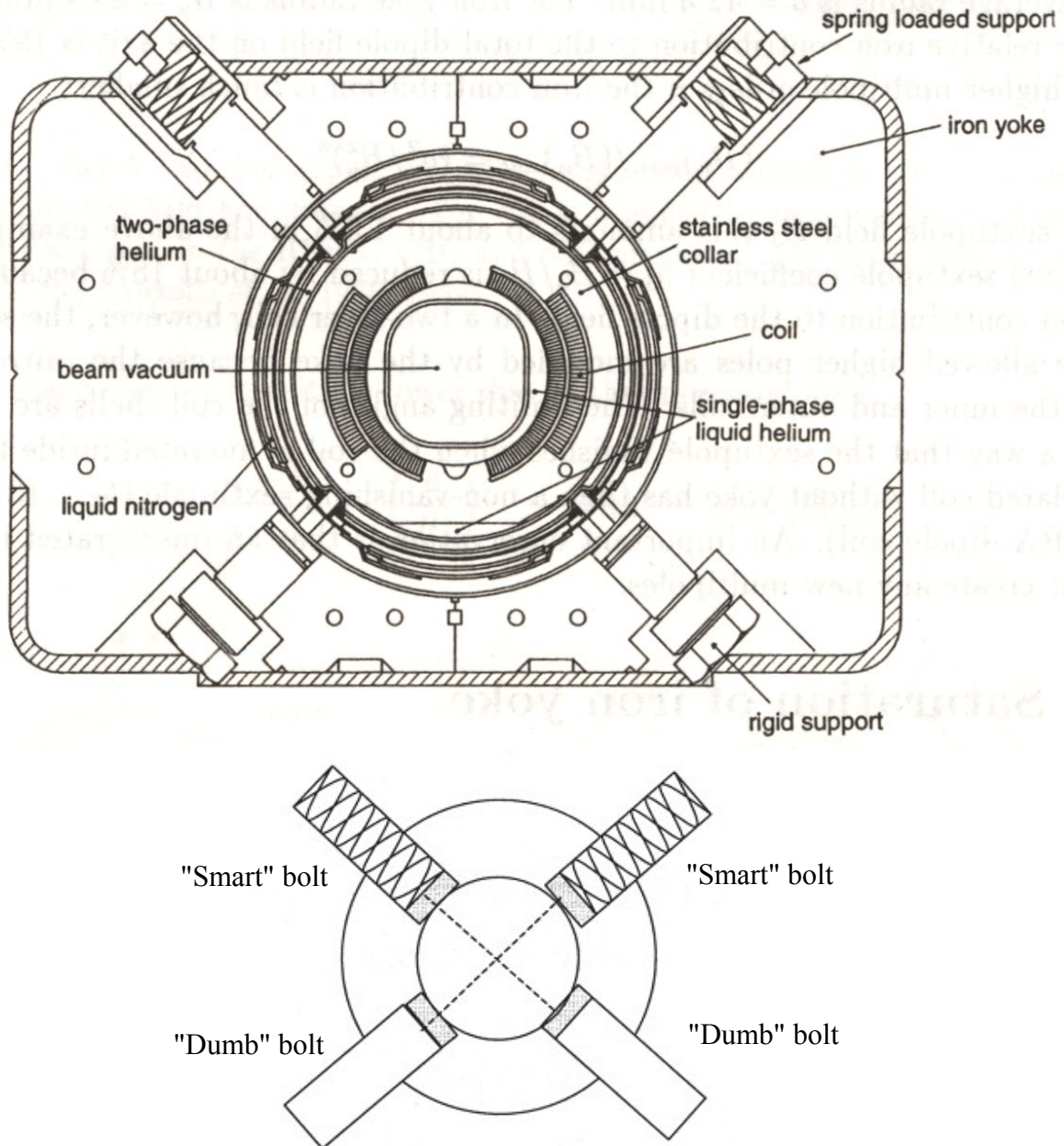


Figure 1: Upper: Tevatron dipole magnet cross-section (in supports area). Lower: Schematic of Tevatron magnet support showing the diagonal smart and dumb bolts as well as the G11 supports.

These stations house the bolts, which are affixed to the yoke and press against the cryostat, and thus the coils along the diagonals. On the topside of the yoke these bolts are called smart, on the bottom side dumb. The dumb bolts are regular bolts. Through the

use of spring cartridges, the positions of the smart bolts are not fixed, but instead are allowed to move as the collared coil diameter changes (i.e. as the collared coil shrinks during cooling, the smart bolts expand to hold the collared coil in place).

Suspension parts list:

124745	Non-anchor smart bolt	124724	Anchor smart bolt
124533	Dumb bolt	124104	Anchor G10 suspension
124291	Floating nut		
126013	TB QI/II outer G11 suspension		
126014	TB QIII/IV outer G11 suspension		
126015	TB/TC QI/II/III/IV inner G11 suspension		
126016	TC QI/II/III/IV outer G11 suspension		

The lower fixed bolts were used to position the collared coil relative to the iron yoke. This positioning is critical to minimize the normal and skew quadrupole harmonics of the magnetic field. The position of the collared coil was adjusted by either adding or removing brass shims, placed between the end of the dumb bolt and the cryostat. Likewise, brass shims were also adjusted on the smart bolts in an equal but opposite direction as the dumb bolts (i.e. a shim that was removed from the dumb bolt was added to the smart bolt, and vice versa). The smart bolt shim adjustments were done to maintain the overall dimension, and therefore the load from the smart bolts, constant. This shimming procedure was successful, resulting in a total skew quadrupole moment in the entire Tevatron dipole magnet population of approximately zero.

The so-called lift measurement is the distance between the upper surface of the smart bolt and the top surface of the push rod inside the smart bolt. Since the smart bolts are hollow, the lift can be measured using a depth probe. The lifts were routinely measured with the magnets at room temperature and liquid helium temperature during magnet assembly and testing, giving rise to the terms warm lift and cold lift.

G10/G11 Creep

The following simple model, illustrated in Figure 2, relates the change of lift to a change of vertical coil position. According to this model, creep occurred in all G10/G11 suspensions². The stiff spring in the top suspensions, however, continued to push the smart bolts against the top supports. As a result the coils are dropping vertically within the yoke at a rate determined by the creep of the bottom suspensions. The lift, however, is a measure of the change of both, the bottom and the top suspensions aligned on each diagonal. To relate the lift to a change in vertical position of the coil an assumption has to be made about the creep of individual suspensions. Assuming that all suspensions crept the same amount, the lift change has to be divided by two to obtain the dimensional change in the bottom suspension. The fact that the suspensions are aligned at 45° then allows calculation of the change of vertical coil position Δy as a function of lift change

$$\Delta d: \Delta y = \left(\frac{\Delta d}{2} \right) \frac{1}{\sin \alpha} = \left(\frac{\Delta d}{2} \right) \frac{1}{\sin 45} = \left(\frac{\Delta d}{2} \right) \sqrt{2} = \frac{\Delta d}{\sqrt{2}} = 0.707 \Delta d \quad (1)$$

² A study of G10 creep was conducted in 1980. A copy of the report is available from <http://tdserver1.fnal.gov/project/Tev-Magnets/Smartbolts/G-10CreepStudy1980.pdf>

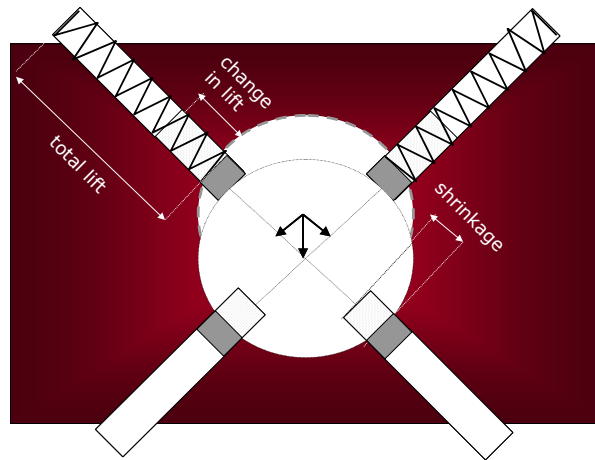


Figure 2: Schematic illustrating the effect of shrinkage of coil supports on lift and coil position.

Figure 3 shows the comparison between the recent cold tunnel lift measurements and the legacy production cold post-reshim measurements. As can be seen, the average change is 5.5 mils, which corresponds to a change in y of 3.9 mils, or a change in skew quadrupole of ~ 1 unit (MTF lift data after January 1983 appear to be corrupt, so they are not used in this calculation).

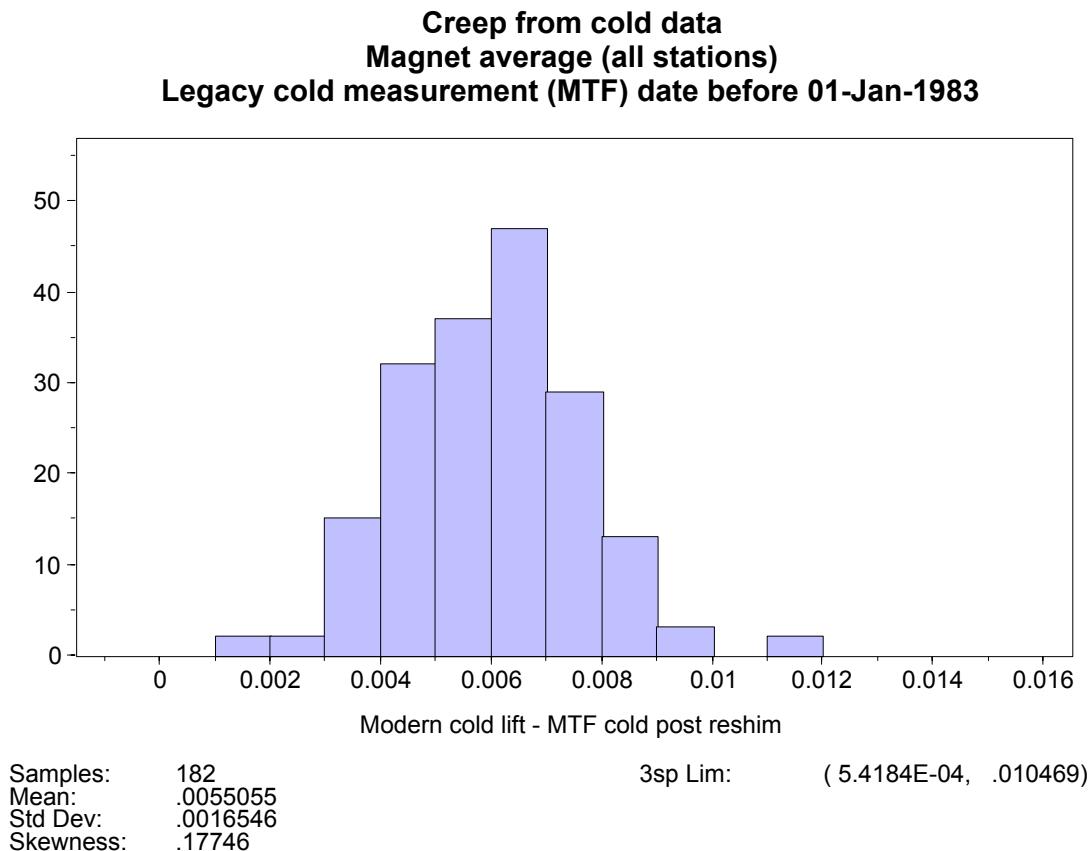


Figure 3: Average cold lift difference for 182 Tevatron dipoles.

The Basic Plan

The plan was to add a four mil brass shim to all the available Q3/Q4 stations in 106 installed dipoles. This size was chosen because the average change in y due to G10/G11 creep was close to four mils, and the magnetic modeling (done by Accelerator Division) showed that the vertical change resulting from a four mil shim would, on average, bring the skew quadrupole harmonic back to zero. The 106 were chosen because they are in regions of the Tevatron lattice where corrections for the skew quadrupole harmonic are not being done. The correction is not being done because “strong” correctors in low-beta spools replaced the “weak” correctors in the normal spools in these regions to create the interaction points at B0 and D0. The locations ranged from A44-2 through A48-5, B11-2 through B19-5, C44-2 through C48-5, and D11-2 through D19-5.

Considerations

What to shim

We say “all available” stations were to be reshimmed because some stations are not accessible due to B2 stands, vacuum pumps, or other obstructions. In IB1 we studied the effects of reshimming seven versus nine stations, and the result was that the difference was nominal. We also considered the possibility of uniquely reshimming each magnet, i.e. the amount of creep for a magnet would determine the shim size for that magnet. Due to inherent variations in the measurements (both legacy and present day), it was decided that this option was not viable (note the width of the distribution in figure 3). We concluded that we should use the average shift for all magnets, since it was a net change that was needed in this region (i.e. we wanted the net change to be across all 106 dipoles together). Therefore, we decided to reshim as many stations as were accessible, knowing that the average change in this region would be the desired change.

Data collection

The quality control of the process depends on accurate lift measurements. With the amount of data being collected in a very short period of time, we decided to use an automated data collection system. We found a system made by Mitutoyo called “Pocket ML.” This system used software made by Mitutoyo, off-the-shelf hardware (digital mics, PDAs running Pocket PC), and Mitutoyo connecting cables. The specific parts are listed in Appendix I “Tooling”. In order to ensure that the data collection, both from the original travelers and for recent measurements, was done accurately, we defined the specifics of how we collect data. The ‘data flow’ processes are described in Appendix III.

Part of the data collection process involves the configuration of the MeasurLink/Pocket ML software. The system is setup to be able to create configuration files (i.e. ‘header’ files) on the PDA, or on the desktop. The best method is to create the header file on the desktop, and then copy it to each PDA. Our header file contained 20 datums, or ‘features’. The first and last features were the calibration checks, and the other 18 were the lift measurements. The calibration features had very tight limits applied so that the software would let the operator know if a measurement did not meet the specification. Due to inherent variations in the lifts and magnet temperatures, as well as the fact that

some stations could not be measured (B2 stands or other obstructions), we were not able to apply limits to each feature.

As described in Appendix III ‘Data flow’, our practice was to save each measurement run as a unique file (i.e. each magnet had one file for the pre-reshim measurement and another file for the post-reshim measurement). These files would then be imported into the MeasurLink database, queried, and copied into our master database for analysis. For details regarding the database structure and queries, refer to Appendix IV.

Data variation

We also needed to understand the variation inherent to this measurement system. As such, we conducted two gage repeatability and reproducibility (GR&R) studies. Each study was conducted with four operators. The first study was done to set a baseline. The operators used their own techniques to calibrate and measure the lifts. The result was a 2 mil R&R ($\sim \pm 3\sigma$). We then adopted a standard methodology, trained all the operators, and conducted the second study. The result was a 0.7 mil R&R, which is more pleasing. The standard methodology incorporated the use of a standard calibration block (part number MB-360298, 1.6505”). Other factors which affect measurement variation: because the opening on the smart bolts is small, the gage extension can easily get hung up on the side of the opening. In order to ensure the extension is not hung up, it is necessary to move the gage around on the surface of the smart bolt, and move the extension up and down until it moves freely. In addition, the extension has a tendency to loosen itself, so it is important to regularly check that it is still screwed in tightly (i.e. after each measurement is a good frequency to check). Note: a subsequent gage study was conducted in the tunnel about a week after the work began. This third study resulted in a 2 mil R&R. This increase in variation appears to have been caused by an increase in operator variation. It was not well understood why operator variation increased, but it could simply have been due to the rigors of the tunnel environment.

Anchor and non-anchor smart bolts

The anchor smart bolts (i.e. station 5) have a much different lift than the non-anchor bolts. Historically this meant placing a different extension on the lift measuring gage. This process increases the possibility that the extensions will not be installed correctly, or they come loose, causing the measurement to be off. To get around this, we made a measurement “collar” (part number MB-360299), which would allow us to use the same 1.5” extension for all measurements. The collar rests on the anchor smart bolt, and the gage rests on the collar. When the data are imported into the master database, the query subtracts the depth of the collar (1.5”) from the recorded measurement.

Ergonomics

The work of reshimming a magnet in the tunnel is very low to the ground, and often there is little clearance over the magnet. This translates into much time being spent on knees bent over the magnet. This introduces quite a bit of strain and fatigue, and so it was very important that we address these issues when planning this work. To help alleviate as much strain as possible, we ordered tooling and PPE specific for this work. We also had our SSO talk with the technicians to remind them of the proper ergonomics for doing this

sort of work. The target work rate of two magnets per day per team was also designed to minimize the strain on the technicians.

Failure Modes

The best way to document all the considerations was to create a Process Failure Modes and Effects Analysis (PFMEA). This tool was used to define and understand the possible failure modes associated with the work. These failure modes were then studied, and the methodology for doing the work was improved, as needed, to mitigate the risks. The PFMEA is Appendix II of this report.

What really happened

We assigned three three-person teams, plus one supervisor. We envisioned each person being cross-trained so that they could fill any role (e.g. everyone would know how to use the data collection tooling). It turned out that each team naturally found one person who was comfortable using the data collection tooling, and the others were happy to do most of the “wrench turning.”

Our estimate was that each team could reshim two magnets per day. With the exception of the the last day, this estimate was accurate (on the last day each team reshimmed three magnets).

Reshimming work in the tunnel began on 09-Sep-2003, and finished 02-Oct-2003 (18 work days). The following table describes the hours and personnel costs spent against task number 30.8.2.06.7.2 for the period from August through November 2003:

Month	Total Personnel Hours	Total Personnel Costs
August 2003	415	\$17,501.64
September 2003	1614.5	\$54,929.72
October 2003	821	\$40,977.03
November 2003	794	\$34,897.09
	3644.5	\$148,305.48

Of course, there was a lot of work done prior to August, but it was charged against 30.8.2.06.2, as were numerous other projects, and so we are not able to tabulate those hours. There has also been time spent after November, but these hours are not directly connected with the tunnel work.

The best estimate for material costs (i.e. tooling, machine shop, et cetera) is about \$16K (see Appendix I “Tooling” for more details). This is an estimate because, with the exception of one \$200 purchase, all purchases were charged against other task numbers.

The tunnel work was done using traveler 333742³. There were a total of 26 discrepancy reports⁴ issued during the project. Below is a summary of the issues found:

³ Travelers are archived in OnBase, and are available by clicking [here](#).

⁴ Discrepancy reports are archived in OnBase, and are available by clicking [here](#).

Issue	Count
“Bad” dumb bolt	8
Shim not added	5
Smart bolt not tightened	4
“Bad” smart bolt	3
“Bad” lift difference	3
Dropped shims	3
Problem from original fabrication	2
Two shims installed	1

The data analysis took much more effort than was planned for. We basically had one full-time person and one half-time person, and this was not enough. It is true that much of the data analysis time was spent investigating the anchor issues discovered as a result of reshimming. However, the proper data management and analysis probably should have been a full-time job. The resources needed to understand the extent of the anchor issues should have been over and above the needs of the “normal” data analysis.

**Cold pre reshim - cold post reshim (tunnel)
Magnet avg difference (without anchors)**

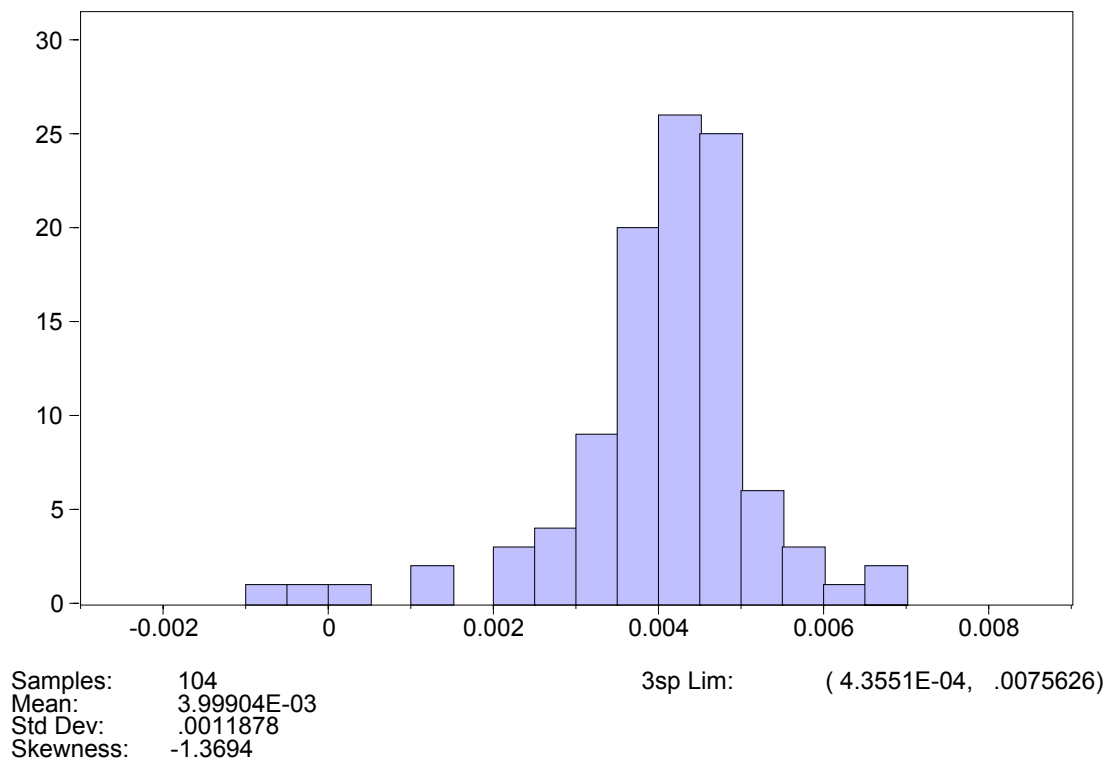


Figure 4: Average difference in cold lift due to reshimming.

Figure 4 above is a histogram showing the pre to post reshim difference in cold lift. Note that two magnets were replaced during the shutdown (TC1130 and TB1136), resulting in there being 104 magnets in the dataset. Anchors are not included here because a problem

with anchors was discovered during this project⁵, and so the anchor data have been removed from this calculation. Attention is also drawn to the five outliers on the left side of the curve. Below are remarks related to those five magnets:

Serial #	Location	Cold Diff.	Cool Diff.	Comment
TB1104	A48-5	-.0008 mil	5 mils	Cold pre reshim looks odd
TB1090	A48-4	-.0004 mil	5 mils	Source of problem not known
TC1021	D13-3	.0003 mil	3 mils	Cold pre reshim looks odd
TB0316	A45-3	1.2 mils	4 mils	Cold pre reshim looks odd
TB0294	D16-2	1.3 mils	2 mils	Cold pre reshim looks odd

Both the spread of the histogram and the comments above give evidence that there are issues with modern measurements. Some of the sources of variation have been identified (refer to *Data Variations* under the **Considerations** section above), but not all variation can be accounted for. Since the measurements are critical to being able to quantify the quality of the work, we must be very diligent when taking and reviewing lift measurements.

Things to remember next time

Much of this was described in the rest of this report, but it makes sense to have them all listed here too:

- Concerning the depth micrometers:
 - The extension easily becomes loose while testing, so it should be regularly tightened.
 - The extension gets hung up on the side of the opening on the smart bolt, so the gage should be moved around while moving the extension up and down until you know the extension moves freely.
 - There is a “Rev” setting on the mic. The “Rev” must be showing on the LCD, or else the movement of the measurement will be in the wrong direction (i.e. having “Rev” on the LCD gives us the right reading). Note that the gage can be calibrated without the “Rev” showing, but then the lift measurements will not be correct.
- Concerning the lift measurements:
 - It became apparent during the project that changes in magnet temperature were causing problems with the quality control measurements (i.e. the lift measurements are dependent on the temperature of the magnet). It doesn’t matter what the temperature is during reshimming, as long as it is constant between the pre and post reshim lift measurements.
 - Anomalies in lift differences from reshimming were often traced back to the pre reshim measurements (both cold and cool). Unfortunately, these “odd” measurements were only discovered after the reshimming was completed, and so they are not recoverable. It is not clear what the source of the problem is, but diligence must be exhibited when making measurements, especially for the measurements which cannot be redone. It

⁵ The anchor problem has been written up in TD Note TD-04-xxx.

would also be good to be able to review the data prior to proceeding with the reshimming, but this may not be practical.

- Concerning the PocketML software:
 - Every time the PDA would be restarted, one needed to “set the port” to RS232 in order for the data collection to work.
 - One must remember to save the data file as an MRT, or else the traceability data will be lost.
 - One can navigate through the various “features” while measuring a magnet. In this way single datums could be retaken and changed. However, after the part is finished (i.e. the magnet is measured and the final calibration check is done), the datums cannot be retaken and changed.
 - The lift measurerer must ensure that the data file is complete. Incomplete data files cause the desktop software (MeasurLink) to crash, and much time must be invested to find the “corrupt” data file.
- Considering the tooling:
 - Towards the end, the pneumatic tools were not being used very much. It seems to have been easier to use a ratchet (either the air ratchet or the torque wrench) to break the bolts loose and remove them. When this work is done again, we should invest in ratcheting breaker bars so that the torque wrenches are not improperly used.
 - If pneumatic tools are used in the future, then goggles should be worn. During this project one technician had something blow in his eye (while wearing safety glasses) while using the pneumatic wrench. After that event anyone using the air tools was required to wear goggles (this most likely also led to the statement above that the air tools were not used much).
- Considering data analysis
 - Data analysis consumed much more time than was initially estimated. This was, in part, due to the anchor problems discovered as a result of reshimming. Anchor problems notwithstanding, however, the effort to upload and review all the data on a daily basis turns out to be at least a full-time job. If we reshim more magnets in the future, we will need to have adequate resource for data analysis (e.g. perhaps graduate students from CDF or D0).

TD-04-004 Appendix I "Tooling"

Description	Quantity	Cost/unit	Total cost	Purchase record
Compaq IPAQ 3950 PDA	4	\$386.63	\$1,546.52	PO551915
CF expansion pack	4	\$83.50	\$334.00	PO551915
IPAQ rugged case	4	\$109.12	\$436.48	PO551915
MeasurLink desktop software	1	\$918	\$918.00	PO551876
Pocket ML software and Input device	4	\$404	\$1,616.00	PO551876
Digital mics #547-217	4	\$318.60	\$1,274.40	PO551876
2m cable with ABS	5	\$37.35	\$186.75	PO551876/PRN38062
Calibration block (MB-360298 rev none)	8	\$66.50	\$532.00	PO552440
Anchor gage block (MB-360299 rev none)	4	\$52.00	\$208.00	PO552440
Dumb bolt measurement gage (MB-360300 rev none)	1	\$105.00	\$105.00	PO552823
Reshimming magnet labels (1.5" diameter)	1000	\$0.26	\$260.00	PO553033
"Dots" for marking reshimmed stations (0.204" diameter)	3000	\$0.11	\$330.00	PO553033
Artwork for reshimming magnet labels	1	\$35.00	\$35.00	PO553033
Plate for reshimming magnet labels	1	\$45.00	\$45.00	PO553033
Tool box (cat # 6571A2)	4	\$47.76	\$191.04	PRN37524
Air compressor (cat # 80057185)	3	\$355.91	\$1,067.73	PRN38176
Air compressor (cat # 4309K96)	1	\$307.69	\$307.69	PRN36784
3/8" ID hose (cat # 9264K12)	7	\$39.20	\$274.40	PRN36784/PO552829
Rubber hose assembly, 25' (cat # 9264K22)	4	\$54.28	\$217.12	PRN38503
Quick disconnect - male (cat # 6534K71)	8	\$1.86	\$14.88	PRN36784/PO552829
Quick disconnect - female (cat # 6536K31)	14	\$8.25	\$115.50	PRN36784/PRN38896/PO552829
Swivel angle pneumatic plug (cat # 52435K17)	8	\$24.73	\$197.84	PRN37524/PO552829
Torque wrench (cat # 85555A712)	9	\$157.06	\$1,413.54	PRN36784/PRN39362/PO552829
0.5" SQ drive (cat # 5283A53)	7	\$240.49	\$1,683.43	PRN36784/PO552829
0.5" SQ drive socket, 1 3/8" (cat # 5545A92)	12	\$11.46	\$137.52	PRN36784/PO552829
0.75" SQ drive socket, 1 5/8" (cat # 5547A24)	12	\$18.18	\$218.16	PRN36784/PO552829
0.75" adapter, 0.5" SQ female to 0.75" SQ male (cat # 5523A38)	12	\$6.93	\$83.16	PRN36784/PO552829
0.5" drive extention, 2.5" (cat # 5523A27)	12	\$7.46	\$89.52	PRN37524/PO552829
"T" handle 1/4" hex key (cat # 5374A18)	8	\$5.38	\$43.04	PO552829
Halogen lights with stand (Home depot)	8	\$8.88	\$71.04	PRN39179/PRN39298
Handheld lights (cat # 91494)	5	\$21.80	\$109.00	PRN38167
Coilzak light sheet (#053320)	1	\$203.75	\$203.75	PRN39036
Extention cord (Home Depot)	4	\$13.97	\$55.88	PRN39298
Stools, fixed height (cat # 2585T12)	4	\$45.28	\$181.12	PRN39300
Knee pads (cat # 5205T11)	18	\$72.79	\$1,310.22	PRN37524/PRN38288/PO552829
NOTE: This total does not include any shipping costs.		Total:	\$15,812.73	



POTENTIAL FAILURE MODE AND EFFECTS ANALYSIS PROCESS FMEA

TD-04-004 Appendix II 'PFMEA'

FMEA Number:
Page 1 of : 2
Customer: BD
Issue Date: 08-Aug-03
Revision Date:

Project No: 30/30.8.2.06.2

Project Name: Tev Dipole Reshimming (0234)

Process Name:

Project Engineer: B. Robotham

Traveler Coordinator: B. Jensen

Core Team: J. Blowers, J. Carson, D. Harding, R. Hanft

Process Step	Potential Failure Mode	Potential Effect(s) of Failure	S	C	Potential Cause(s) of Failure	O	Current Process Controls	D	R P N	Recommended Action(s)	Responsibility & Target Completion Date	Action Results					R P N
												Action(s) Taken	S	O	D		
Identify magnets to be reshimmed	Wrong magnets identified	Documentation mismatch			Database not up to date		TD verified BD list										
		Not all magnets reshimmed			Typographical error Misread list												
Create shim kits	Wrong thickness	Bad harmonics	2		Shims not measured		Every shim is being measured										
		Put coils too far off center	2	Shims mismeasured	Measurer training												
				Shims put into wrong bag	Measurer training												
Collect historic data	Data not collected	No comparison can be made			Travelers/pages not available		None										
	Wrong data collected	Comparison is incorrect			List is incomplete or misread	None	Compare dbs with lift list	J. Blowers									
					Data entry error	Review data											
Collect lift measurements	Gauge miscalibrated Gauge not in correct position for measurement	Data incorrect, leading to wrong conclusions			Calibration not done		Training										
					Improper calibration technique		Training										
					Material on bolt surface Gauge not placed flush on surface		Cleaning of surface Training										
	PDA fails	Loss of data			Battery runs out		Charge batteries over lunch break		Save data to CF card	J. Blowers							
Upload measurements to dbs	Software not working	Data cannot be directly uploaded			Computer malfunction		None										
	Data not uploaded	Data loss, or data errors			Person or PC not available		Training of more than one person to do uploads										
Review/compare data	Wrong data compared	Incorrect conclusions drawn			Wrong query used		Training										
					Query code is incorrect		Previous validation of query										
					Data erased	No conclusions can be drawn											
	Dbs erased	Backups															
	Data erased	Backups															

PROCESS FMEA

Part Name: Tev Dipole Reshimming (0234)					PFMEA Number: 0					Page 2 of 2							
Process Purpose	Potential Failure Mode	Potential Effect(s) of Failure	S	C	Potential Cause(s) of Failure	O	Current Process Controls	D	R P N	Recommended Action(s)	Responsibility & Target Completion Date	Action Results					R P N
												Action(s) Taken	S	O	D		
Issue traveler and kits	Wrong traveler	Can't do work			Wrong spec issued		Verification of traveler										
	Kit incorrect	Wrong shim applied			Mismeasure		Training										
		Not enough shims			Incorrect shim count		Extra shims										
Reshimming	Not all bolts reshimmed	Harmonics not corrected			Traveler not followed		Traveler/training; all magnets will be checked for sticker at end of project			Consider using toolmaker paint to identify shims and/or stickers applied to smart bolts	B. Robotham						
					Not enough shims in kit		Traveler/training										
	Too much shim added	Harmonics overcorrected		Shim packs incorrect		Training/lift inspections											
				Two shims stuck together		Training											
				Coils put too far off center		Poor measurements or production data		Training; review of old data									
	Not enough shim added	Harmonics not corrected			Shim packs incorrect		Training/lift inspections										
	Bolts undertightened	Cryostat too loose		Malfunctioning tool		None											
				Torque not set properly		Training											
	Bolts overtightened	None		Malfunctioning tool		None											
				Torque not set properly		Training											
	Debris put into magnet	None		Dropped shim		None		Tray/mat under magnet?	B. Robotham								
				Failure to clean smart bolt well		Traveler/training											
	Stripped threads	Replace bolt			Screwing in bolt at angle		Training		Spare parts ready to go in tunnel	B. Robotham							
	Not all magnets reshimmed	Harmonics not corrected			Documentation mix up		Documentation verification										
	Wrong shims added	Harmonics not corrected			Shim pask dropped, and shims lost		Training/lift inspections		Extract data as needed	J. Blowers							
Vertical plane changed too much	Magnet needs to be realigned			Effect of lossening and tightening bolts		Studies being done		Possible change the work pattern	J. Carson								
Tools fail/break	Down time			Mfg defect/misuse		Spare tooling											
Radiation safety	Contamination	Overexposure			Not following procedure		Rad Worker training			RSO to speak with teams	J. Blowers						
Ergonomics	Repetative strain	Injury			Work too strenuous		PPE/tooling/training			SSO speak with teams re ergonomics	J. Blowers						
	Physical exhaustion	Poor work quality															

Tevatron magnet lift data flow

Data retrieval: Process for retrieving data from the original travelers

Step	Data location
1. Identify serial number of device(s) for data collection.	
2. Identify records management box number in which the original travelers are stored.	smart_bolt_data.mdb (use the query 'prompt serial number for RM box')
3. Determine if the box needs to be recalled from RM, or if it is already in TD.	smart_bolt_data.mdb (use the query 'prompt serial number for RM box'). NOTE: If the ShippingDate or ShippedInOut fields are blank, then the box is in records storage and will need to be ordered.
4. If the box is already in TD, then proceed to step 6. If the box needs to be recalled, send an e-mail request to Marilyn Dixon. Boxes are normally delivered on Thursdays.	
5. When the box is received, log it into the RM database.	ProEng2000DocumentStorageRecord.mdb
6. Identify and remove all the assembly and MTF travelers from the box.	
7. Enter the following information into the database: - All warm lift measurements - All cold lift measurements - Warm and cold shim corrections	smart_bolt_data.mdb (use the forms 'lift_entry' and 'Shims_entry')

New measurements: Process for collecting new lift measurement data

Step	Data location
1. Identify serial number of device(s) for data collection.	
2. Take the measurements and record the data. Data has been recorded on paper, but in the near future we will be able to collect the data directly from the gauge into a PDA.	Paper forms and/or an iPAQ running Pocket ML (Mitutoyo data collection software)

3. Load the data into the database. The data recorded on paper needs to be hand keyed. The data in the PDA needs to go through the steps 3a through 3e. It should be noted that at this time these steps can only be done on TDPC63 (Jamie Blowers), since that is where the software is installed.	For paper forms use forms 'lift_entry' and 'Shims_entry' in smart_bolt_data.mdb
3a. From Pocket ML, select Run Save As..., and save the file as a .mrt.	PDA
3b. Dock the PDA in its cradle.	
3c. Copy the mrt file over to the PC.	
3d. Open the Data Collection module of MeasurLink Real Time, and select Tools Import to import the mrt file. Browse to find the file and select it. Click OK to import the data.	<p>MeasurLink Real Time Data Collection. The data will reside in the Sybase SQL database running in the background (MeasurLink50.db).</p> <p>Once the data are in the Sybase database, it can be queried and extracted using ODBC.</p>
3e. Query the MeasurLink database, and copy the data into the smart bolt data table.	Use query 'measurlink3' in the database smart_bolt_data.mdb to retrieve the data. Copy the data into the table 'smart_bolt_data_primary_table'.
4. Run the appropriate query to compare recent measurements with historical data.	Right now I use the query 'Difference_calculation-cold-dipoles' in the database smart_bolt_data.mdb. Other queries should be developed, as needed.

TD-04-004 Appendix IV

Database structure

Central database

The central database was MS-Access. This was chosen because of its ease of use and the fact that every PC has it installed. It is also easy to connect MS-Excel and Quality Analyst to MS-Access. The fields in the table 'smart_bolt_data_primary_table' are listed here:


Field Name	Data Type	Description
Autonumber	AutoNumber	
Serial_Number	Text	Serial number of device
RM_Box	Text	Records Management box number
Location	Text	Location where measurement was taken
Date	Date/Time	Date of measurement
Time	Date/Time	Time of measurement
Technician	Text	Name of technician who made the measurement
Temperature	Text	Warm or cold measurement?
Reshim	Text	Pre or post reshim
T_Value	Number	Temperature at beginning of measurement (K)
Gauge	Text	Gauge used to take measurements
Data_descriptor	Text	Description of where data is from
Assessment	Text	Assessment of data
Comment	Memo	Comment about measurement
Q1-1	Number	Quadrant 1, location 1
Q1-2	Number	Quadrant 1, location 2
Q1-3	Number	Quadrant 1, location 3
Q1-4	Number	Quadrant 1, location 4
Q1-5	Number	Quadrant 1, location 5
Q1-6	Number	Quadrant 1, location 6
Q1-7	Number	Quadrant 1, location 7
Q1-8	Number	Quadrant 1, location 8
Q1-9	Number	Quadrant 1, location 9
Q2-1	Number	Quadrant 2, location 1
Q2-2	Number	Quadrant 2, location 2
Q2-3	Number	Quadrant 2, location 3
Q2-4	Number	Quadrant 2, location 4
Q2-5	Number	Quadrant 2, location 5
Q2-6	Number	Quadrant 2, location 6
Q2-7	Number	Quadrant 2, location 7
Q2-8	Number	Quadrant 2, location 8
Q2-9	Number	Quadrant 2, location 9

Queries used for data analysis were based on the data contained in this main table.

Mitutoyo database

In order to get the data into the above table, it had to be uploaded into the Mitutoyo database, extracted and copied into the MS-Access database. The Mitutoyo software (MeasurLink) uses Sybase SQL Anywhere as its backend. The data were uploaded from the PDAs to the database using the desktop software and the MRT files. Once loaded in the Sybase database, they could be queried using MS-Access, and copied into the primary table. The tables used in the MeasurLink queries are listed here:

TD-04-004 Appendix IV
Database structure

- ✦  DBA_RT110CFR
- ✦  DBA_RT110CNT
- ✦  DBA_RT110CSN
- ✦  DBA_RT110CTR
- ✦  DBA_RT110CTT
- ✦  DBA_RT110CVD

The queries used to extract the data are listed below. Due to the complexity of the data structure, we needed to use nested queries. The 'measurlink3' query was the query which put the data in its final format for copying into the primary table.

Query 'measurlink1':

```
TRANSFORM First(DBA_RT110CVD.OBSERVATION_VAL) AS
FirstOfOBSERVATION_VAL
SELECT DBA_RT110CFR.PART_ID, DBA_RT110CFR.FEATURE_ID,
DBA_RT110CSN.SERIAL_NO, DBA_RT110CVD.SUBGROUP_NO, p.TRACE_ITEM
AS Data_descriptor, DBA_RT110CTR.SUBG_TIMESTAMP, loc.TRACE_ITEM AS
Location, T1.TRACE_ITEM AS Technician1, T2.TRACE_ITEM AS Technician2,
T3.TRACE_ITEM AS Technician3, G.TRACE_ITEM AS Gauge
FROM DBA_RT110CTT AS G INNER JOIN (DBA_RT110CTT AS T3 INNER JOIN
(DBA_RT110CTT AS T2 INNER JOIN (DBA_RT110CTT AS T1 INNER JOIN
(DBA_RT110CTT AS loc INNER JOIN (DBA_RT110CTT AS p INNER JOIN
(DBA_RT110CTR INNER JOIN (DBA_RT110CSN INNER JOIN (DBA_RT110CFR
INNER JOIN DBA_RT110CVD ON DBA_RT110CFR.FEATURE_RUN_NO =
DBA_RT110CVD.FEATURE_RUN_NO) ON (DBA_RT110CSN.OBSERVATION_NO
= DBA_RT110CVD.OBSERVATION_NO) AND
(DBA_RT110CSN.FEATURE_RUN_NO = DBA_RT110CVD.FEATURE_RUN_NO)
AND (DBA_RT110CSN.SUBGROUP_NO = DBA_RT110CVD.SUBGROUP_NO)) ON
(DBA_RT110CTR.SUBGROUP_NO = DBA_RT110CVD.SUBGROUP_NO) AND
(DBA_RT110CTR.FEATURE_RUN_NO = DBA_RT110CVD.FEATURE_RUN_NO))
ON (p.SUBGROUP_NO = DBA_RT110CVD.SUBGROUP_NO) AND
(p.FEATURE_RUN_NO = DBA_RT110CVD.FEATURE_RUN_NO)) ON
(loc.FEATURE_RUN_NO = DBA_RT110CVD.FEATURE_RUN_NO) AND
(loc.SUBGROUP_NO = DBA_RT110CVD.SUBGROUP_NO)) ON
(T1.FEATURE_RUN_NO = DBA_RT110CVD.FEATURE_RUN_NO) AND
(T1.SUBGROUP_NO = DBA_RT110CVD.SUBGROUP_NO)) ON
(T2.FEATURE_RUN_NO = DBA_RT110CVD.FEATURE_RUN_NO) AND
(T2.SUBGROUP_NO = DBA_RT110CVD.SUBGROUP_NO)) ON
(T3.FEATURE_RUN_NO = DBA_RT110CVD.FEATURE_RUN_NO) AND
(T3.SUBGROUP_NO = DBA_RT110CVD.SUBGROUP_NO)) ON (G.SUBGROUP_NO
= DBA_RT110CVD.SUBGROUP_NO) AND (G.FEATURE_RUN_NO =
DBA_RT110CVD.FEATURE_RUN_NO)
WHERE (((p.TRACE_LIST) Like "Traveler*") AND ((DBA_RT110CFR.PART_ID) Like
"*" & "dip" & "*") AND ((loc.TRACE_ITEM) Like "other" Or (loc.TRACE_ITEM) Like
"A*" Or (loc.TRACE_ITEM) Like "B*" Or (loc.TRACE_ITEM) Like "C1*" Or
```

TD-04-004 Appendix IV
Database structure

```
(loc.TRACE_ITEM) Like "C2*" Or (loc.TRACE_ITEM) Like "C3*" Or  
(loc.TRACE_ITEM) Like "C4*" Or (loc.TRACE_ITEM) Like "D*" Or  
(loc.TRACE_ITEM) Like "E*" Or (loc.TRACE_ITEM) Like "F*") AND  
((T1.TRACE_LIST) Like "Technician 1") AND ((T2.TRACE_LIST) Like "Technician 2")  
AND ((T3.TRACE_LIST) Like "Technician 3") AND ((G.TRACE_LIST) Like "Gauge"))  
GROUP BY DBA_RT110CFR.PART_ID, DBA_RT110CFR.FEATURE_ID,  
DBA_RT110CSN.SERIAL_NO, DBA_RT110CVD.SUBGROUP_NO, p.TRACE_ITEM,  
DBA_RT110CTR.SUBG_TIMESTAMP, (p/TRACE_ITEM), loc.TRACE_ITEM,  
T1.TRACE_ITEM, T1.TRACE_LIST, T2.TRACE_ITEM, T3.TRACE_ITEM,  
G.TRACE_ITEM  
ORDER BY DBA_RT110CTR.SUBG_TIMESTAMP  
PIVOT DBA_RT110CVD.OBSERVATION_NO;
```

Query 'measurlink2':

```
TRANSFORM Last(measurlink1.[1]) AS LastOf1  
SELECT measurlink1.SERIAL_NO, DateValue([SUBG_TIMESTAMP]) AS [Date],  
Left([Data_descriptor],4) AS Temperature, measurlink1.Data_descriptor,  
Left([measurlink1]![Location],5) AS Location, [measurlink1]![Technician1] & ', ' &  
[measurlink1]![Technician2] & ', ' & [measurlink1]![Technician3] AS Technician,  
measurlink1.Gauge, Right([measurlink1]![Location],6) AS SN_check,  
Last(TimeValue([SUBG_TIMESTAMP])) AS [Time]  
FROM measurlink1  
WHERE (((measurlink1.FEATURE_ID) Not Like 'cal*') AND ((measurlink1.[1])<100))  
GROUP BY measurlink1.SERIAL_NO, DateValue([SUBG_TIMESTAMP]),  
Left([Data_descriptor],4), measurlink1.Data_descriptor, Left([measurlink1]![Location],5),  
[measurlink1]![Technician1] & ', ' & [measurlink1]![Technician2] & ', ' &  
[measurlink1]![Technician3], measurlink1.Gauge, Right([measurlink1]![Location],6)  
PIVOT measurlink1.FEATURE_ID;
```

Query 'measurlink3':

```
SELECT measurlink2.SERIAL_NO, measurlink2.Location, measurlink2.Date,  
measurlink2.Time, measurlink2.Temperature, measurlink2.Data_descriptor,  
measurlink2.Technician, measurlink2.Gauge, measurlink2.[Q1-1], measurlink2.[Q1-2],  
measurlink2.[Q1-3], measurlink2.[Q1-4], [Q1-5]-1.5 AS Q1_5, measurlink2.[Q1-7],  
measurlink2.[Q1-8], measurlink2.[Q1-9], measurlink2.[Q2-1], measurlink2.[Q2-2],  
measurlink2.[Q2-3], measurlink2.[Q2-4], [Q2-5]-1.5 AS Q2_5, measurlink2.[Q2-6],  
measurlink2.[Q2-7], measurlink2.[Q2-8], measurlink2.[Q2-9], measurlink2.[Q1-6],  
Right([Data_descriptor],4) AS Reshim  
FROM measurlink2  
WHERE (((measurlink2.Date)>#3/14/2004#));
```

Note: the use of the WHERE statement which filters by date is optional. This was used to limit the number of records returned.

Data analysis queries

One of the issues that we encountered was that we needed to be able to identify the last measurement made (chronologically) for any particular data set (e.g. the last cold tunnel measurement). The “last” function in MS-Access did not work 100% of the time, so we developed the appropriate queries using SQL code. An example of this is below:

Query ‘Last_cold_tunnel’:

```
SELECT n.Serial_Number, n.Location, n.Date, n.[Q1-1], n.[Q1-2], n.[Q1-3], n.[Q1-4],
n.[Q1-5], n.[Q1-6], n.[Q1-7], n.[Q1-8], n.[Q1-9], n.[Q2-1], n.[Q2-2], n.[Q2-3], n.[Q2-4],
n.[Q2-5], n.[Q2-6], n.[Q2-7], n.[Q2-8], n.[Q2-9]
FROM smart_bolt_data_primary_table AS n
WHERE (((n.Serial_Number) Like "TB*" Or (n.Serial_Number) Like "TC*" Or
(n.Serial_Number) Like "TD*")) AND ((n.Date)=(select max(p.date)
FROM smart_bolt_data_primary_table AS p
WHERE ( (n.Serial_Number=p.Serial_Number)
AND (n.Temperature=p.Temperature) AND (n.Reshim=p.Reshim)
AND (p.Location=n.Location) ) )) AND ((n.Temperature)="Cold") AND
((n.Data_descriptor)="Cold - tunnel") AND ((n.Reshim)="Pre"))
ORDER BY n.Serial_Number, n.Date;
```

This type of query was replicated for all data descriptors (e.g. last warm production, last production pre reshim, last tunnel post reshim, et cetera). These queries were then used as the basis for making the various calculations, an example of which is below:

Query for creep calculation:

```
SELECT Last_cold_post_reshim_production.Serial_Number,
Right([Last_cold_post_reshim_production].[Serial_Number],4) AS Serial,
Last_cold_tunnel.Location, smart_bolt_list.RM_Box,
Last_cold_post_reshim_production.Date, Last_cold_post_reshim_production.[Q1-1] AS
[Q1-1P], Last_cold_tunnel.[Q1-1] AS [Q1-1T], [Q1-1T]-[Q1-1P] AS [Q1-1_Diff],
Last_cold_post_reshim_production.[Q1-2] AS [Q1-2P], Last_cold_tunnel.[Q1-2] AS [Q1-
2T], [Q1-2T]-[Q1-2P] AS [Q1-2_Diff], Last_cold_post_reshim_production.[Q1-3] AS
[Q1-3P], Last_cold_tunnel.[Q1-3] AS [Q1-3T], [Q1-3T]-[Q1-3P] AS [Q1-3_Diff],
Last_cold_post_reshim_production.[Q1-4] AS [Q1-4P], Last_cold_tunnel.[Q1-4] AS [Q1-
4T], [Q1-4T]-[Q1-4P] AS [Q1-4_Diff], Last_cold_post_reshim_production.[Q1-5] AS
[Q1-5P], Last_cold_tunnel.[Q1-5] AS [Q1-5T], [Q1-5T]-[Q1-5P] AS [Q1-5_Diff],
Last_cold_post_reshim_production.[Q1-6] AS [Q1-6P], Last_cold_tunnel.[Q1-6] AS [Q1-
6T], [Q1-6T]-[Q1-6P] AS [Q1-6_Diff], Last_cold_post_reshim_production.[Q1-7] AS
[Q1-7P], Last_cold_tunnel.[Q1-7] AS [Q1-7T], [Q1-7T]-[Q1-7P] AS [Q1-7_Diff],
Last_cold_post_reshim_production.[Q1-8] AS [Q1-8P], Last_cold_tunnel.[Q1-8] AS [Q1-
8T], [Q1-8T]-[Q1-8P] AS [Q1-8_Diff], Last_cold_post_reshim_production.[Q1-9] AS
[Q1-9P], Last_cold_tunnel.[Q1-9] AS [Q1-9T], [Q1-9T]-[Q1-9P] AS [Q1-9_Diff],
Last_cold_post_reshim_production.[Q2-1] AS [Q2-1P], Last_cold_tunnel.[Q2-1] AS [Q2-
1T], [Q2-1T]-[Q2-1P] AS [Q2-1_Diff], Last_cold_post_reshim_production.[Q2-2] AS
```

TD-04-004 Appendix IV Database structure

```
[Q2-2P], Last_cold_tunnel.[Q2-2] AS [Q2-2T], [Q2-2T]-[Q2-2P] AS [Q2-2_Diff],
Last_cold_post_reshim_production.[Q2-3] AS [Q2-3P], Last_cold_tunnel.[Q2-3] AS [Q2-
3T], [Q2-3T]-[Q2-3P] AS [Q2-3_Diff], Last_cold_post_reshim_production.[Q2-4] AS
[Q2-4P], Last_cold_tunnel.[Q2-4] AS [Q2-4T], [Q2-4T]-[Q2-4P] AS [Q2-4_Diff],
Last_cold_post_reshim_production.[Q2-5] AS [Q2-5P], Last_cold_tunnel.[Q2-5] AS [Q2-
5T], [Q2-5T]-[Q2-5P] AS [Q2-5_Diff], Last_cold_post_reshim_production.[Q2-6] AS
[Q2-6P], Last_cold_tunnel.[Q2-6] AS [Q2-6T], [Q2-6T]-[Q2-6P] AS [Q2-6_Diff],
Last_cold_post_reshim_production.[Q2-7] AS [Q2-7P], Last_cold_tunnel.[Q2-7] AS [Q2-
7T], [Q2-7T]-[Q2-7P] AS [Q2-7_Diff], Last_cold_post_reshim_production.[Q2-8] AS
[Q2-8P], Last_cold_tunnel.[Q2-8] AS [Q2-8T], [Q2-8T]-[Q2-8P] AS [Q2-8_Diff],
Last_cold_post_reshim_production.[Q2-9] AS [Q2-9P], Last_cold_tunnel.[Q2-9] AS [Q2-
9T], [Q2-9T]-[Q2-9P] AS [Q2-9_Diff]
FROM smart_bolt_list INNER JOIN (Last_cold_post_reshim_production INNER JOIN
Last_cold_tunnel ON Last_cold_post_reshim_production.Serial_Number =
Last_cold_tunnel.Serial_Number) ON smart_bolt_list.[S/N] =
Last_cold_post_reshim_production.Serial_Number
WHERE (((Last_cold_post_reshim_production.Serial_Number) Not Like "TC0407" And
(Last_cold_post_reshim_production.Serial_Number) Not Like "TB0507" And
(Last_cold_post_reshim_production.Serial_Number) Not Like "TC0544") AND
((Last_cold_tunnel.Location) Not Like "E48*"))
ORDER BY Last_cold_post_reshim_production.Date;
```

These queries were then linked to Quality Analyst (statistics software) for data analysis.

MS-Excel charting

In addition, certain charts were generated using MS-Excel. The central table was linked to a spreadsheet, and calculations were performed on the data. To get the data in the right format for charting, the following functions were used:

We had to define the data descriptors which we wanted to use for our calculations. This was the list used as of the writing of this report:

2341	Warm - production
2348	Cold post reshim
	Cold pre reshim
	Cold - tunnel Pre
	Cool pre reshim
	Cool post reshim
	Warm - tunnel
	Cold - tunnel Post

The numbers in the upper left are row numbers in the main spreadsheet, and were different for each magnet. They were determined through the following code (cell A1 contains the dipole for which charts are desired):

```
First number:      =MATCH($A$1,'All dipole data'!$A:$A,0)
Second number:    =MATCH($A$1,'All dipole data'!$A:$A,1)
```

TD-04-004 Appendix IV Database structure

Data for the specific magnet were listed as follows:

0Title	Q1-1	...
904TB0993 Production, Warm - production	1.616	...
903TB0993 Production, Cold post reshim	1.632	...
902TB0993 Production, Cold pre reshim	1.638	...
900TB0993 D12-2, Cold - tunnel Pre	1.6405	...
898TB0993 D12-2, Cool pre reshim	1.637	...
896TB0993 D12-2, Cool post reshim	1.632	...
#N/A	#N/A	#N/A
895TB0993 D12-2, Cold - tunnel Post	1.634	...

(Note: the #N/As are present because there are no warm tunnel measurements for this magnet).

The code to generate the row numbers, title and data for all data types except the 'Cold – tunnel Pre' and 'Cold – tunnel Post' is:

Row numbers:

=A\$34+MATCH(B34,INDIRECT("'"&All dipole data!"&E"&A\$34&":E"&FIXED(A\$35,0,TRUE))),0)-1

(Note: the cell A34 stays the same while the cell B34 increases to capture each data type, i.e. each data descriptor defined above).

Title:

=OFFSET('All dipole data'!\$A\$1,\$A3-1,9)

(Note: the cell A3 increases to capture each data type).

Datum:

=IF(ISNUMBER(OFFSET('All dipole data'!\$A\$1,\$A3-1,14+COLUMN()-COLUMN(\$C3))),OFFSET('All dipole data'!\$A\$1,\$A3-1,14+COLUMN()-COLUMN(\$C3)),NA())

Station (e.g. Q1-1):

=OFFSET('All dipole data'!\$A\$1,\$A2,14+COLUMN()-COLUMN(\$C2))

The row numbers for the pre and post reshimming (because those descriptors are a concatenation of two fields) is generated by:

=A\$34+MATCH(B37,INDIRECT("'"&All dipole data!"&AH"&A\$34&":AH"&FIXED(A\$35,0,TRUE))),0)-1

Calculations of pre to post reshimming, and subsequent charting, can then easily be accomplished through arithmetic calculations.